Displacement Damage Effect Due to Neutron and Proton Irradiations on CMOS Image Sensor

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Overview

Goal : Study of **displacement damage** effects on **CMOS sensors** manufactured in a **deep sub-micron** technology **dedicated to imaging** applications

Test structures : pixel arrays + isolated large photodiodes

Main result :

- Main damage due to displacement is **dark current increase**
- Proton displacement effect
- Neutron and proton induce **equivalent** displacement damage
- Analytic model, based on damage energy, could predict dark current increase distribution in APS
- Defects responsible of dark current increase are **intrinsic defects** probably in the form of **cluster**

Experimental

Test chip :

- 0.18 µm CMOS **CIS** technology
- **Dedicated photodiode** doping profiles
- 128 x 128 pixel arrays, **3T**, 10µm pitch
- Larges photodiodes (>10^4 µm²)

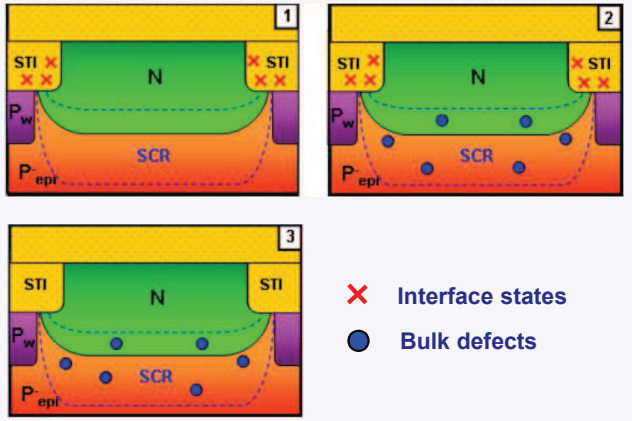
Proton irradiation :

- Facilities : KVI, UCL, TRIUMF
- Energies : **50 to 500 MeV**
- Fluences : 5 x 10^9 to 1 x 10^{11} H^+/cm^2

Neutron irradiation :

- Facilities : CEA Valduc, UCL
- Energies : **0.8 to 20 MeV**
- Fluences : 5 x 10^9 to 1 x 10^{13} N/cm²

Effects on in-pixel photodiode

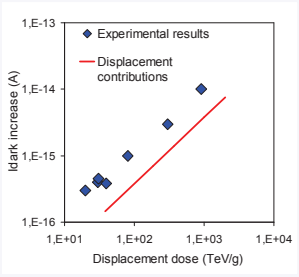


Main defects inducing **dark current increase** in photodiode, after **γ-ray** (1), **proton** (2) and **neutron** (3) irradiations :

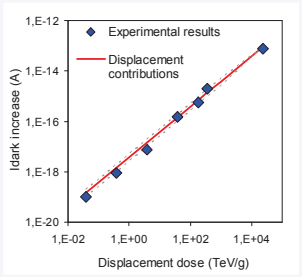
- **Ionization** induces **interface states** in Shallow Trench Isolation (STI)
- **Displacement** induces **point defects** and **clusters of defects** in space charge region (SCR)

Effects on CMOS sensors

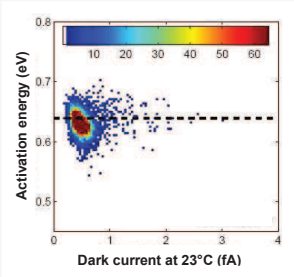
- **No photoresponse degradation, no voltage shift, no gain reduction**



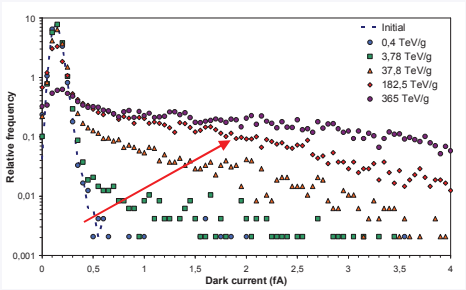
Proton induced displacement damages effects on mean dark current are **negligible** in front of **ionizing dose**



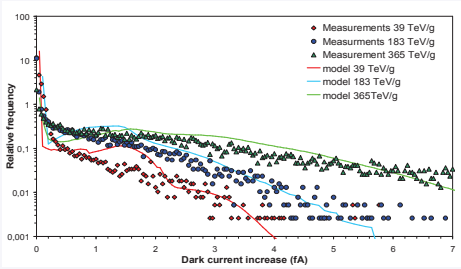
Neutron induces essentially **Displacement damages**



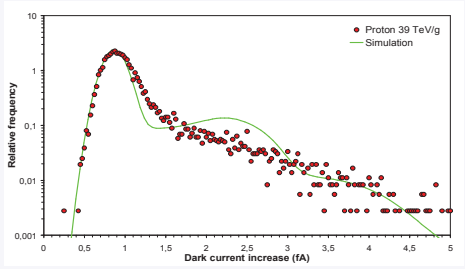
No sign of electric field enhancement at the Si-STI interface



Pixel tail, due to neutron induced displacement, **increases** following **displacement damage dose**

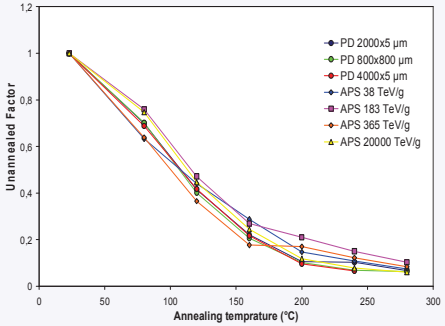


- Histogram observations of **dark current increase** due to **neutron irradiation** are compared to estimates based on **GEANT 4** calculations of the **recoil spectrum parameters**
- **Estimation of dark current increase** is calculated using **the recoil element damage energy**



- **Proportionality** between **damage energy** and **dark current increase** based on **NIEL** is used
- **Analytic model** is convolved with **ionization fit** to obtain **proton induced dark current increase distribution.**

Annealing



Unannealed dark current fraction and **DLTS** measurements show that defects inducing dark current increase could be probably in the form of **clusters**

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